STATE OF DELAWARE

UNIVERSITY OF DELAWARE

DELAWARE GEOLOGICAL SURVEY

REPORT OF INVESTIGATIONS NO. 18

GEOLOGY AND GROUND WATER, UNIVERSITY OF DELAWARE, NEWARK, DELAWARE

BY

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ABSTRACT

The results of an intensive ground-water study on University of Delaware lands in the Newark area revealed additional sources of available ground water. Geophysical techniques, air-photo interpretation, studies of existing data, field mapping, test drilling, and pump tests were used as the bases for guiding additional well development.

The study, conducted by the Delaware Geological Survey, was a cooperative effort between the University of Delaware and the City of Newark in response to mutual water supply problems.

A potential ground-water yield of about 500 gpm was discovered on the University Laird Tract in the Piedmont Province. Ground water available from other locations in the Coastal Plain portion of the study area may total about 175 gpm. However, careful well development and proper well spacing will be necessary to obtain optimum yields.

INTRODUCTION

Purpose and Scope

This report documents new information about the geology and ground-water resources of the University of Delaware's lands within the City of Newark. Particular emphasis is placed on contributions that could be made to the City's water supply by ground-water withdrawals from University property. The study is also an example of the application of geologic techniques to the exploration for ground water in an area of varied terrane that cannot be considered to have abundant ground-water resources.

The City of Newark, with a 1970 population of 21,500, is Delaware's second largest city. The University of Delaware is located within the City and has a total student population of 16,800; its properties total approximately 1,082 acres within or close to the City.

Newark's water supply is obtained from wells located in the southern portion of the City and in the suburban area farther to the south. Total water use during 1970 averaged about three million gallons per day (mgd). Part of the well production was supplemented by the purchase of additional water from the surface water supply of the Delaware Water Company.

In recognition of the mutual problems of water supply shared by the University of Delaware and the City of Newark, President E. A. Trabant approved, on January 20, 1971, the creation of the University of Delaware Ground-Water Exploration Committee. The Committee, comprising Dr. Donald F. Crossan, Chairman, Mr. Leonard Cannatelli, Mr. John W. Grundy, Dr. Robert R. Jordan, and Dr. Robert D. Varrin, coordinated by Vice President George M. Worrilow, directed the study presented in this report. The basic charge to the Committee was to assess the potential ground-water resources of University-owned lands in and adjacent to the City of Newark (Figure 1). Implementation of the study, including field work, laboratory analyses, and report preparation, has been provided by the Delaware Geological Survey (DGS).

This report presents the findings of the investigation conducted in the spring of 1971. The geology and hydrology of the area are discussed and those areas having the greatest ground-water potentials are defined. The most promising areas for immediate development have been pump-tested and the analyses of these tests are presented as bases for the design of final production wells. Much additional data, including geophysical well logs and surface surveys, pump test data plots, and over 350 samples are retained in the files and collections of the DGS as permanent reference materials.

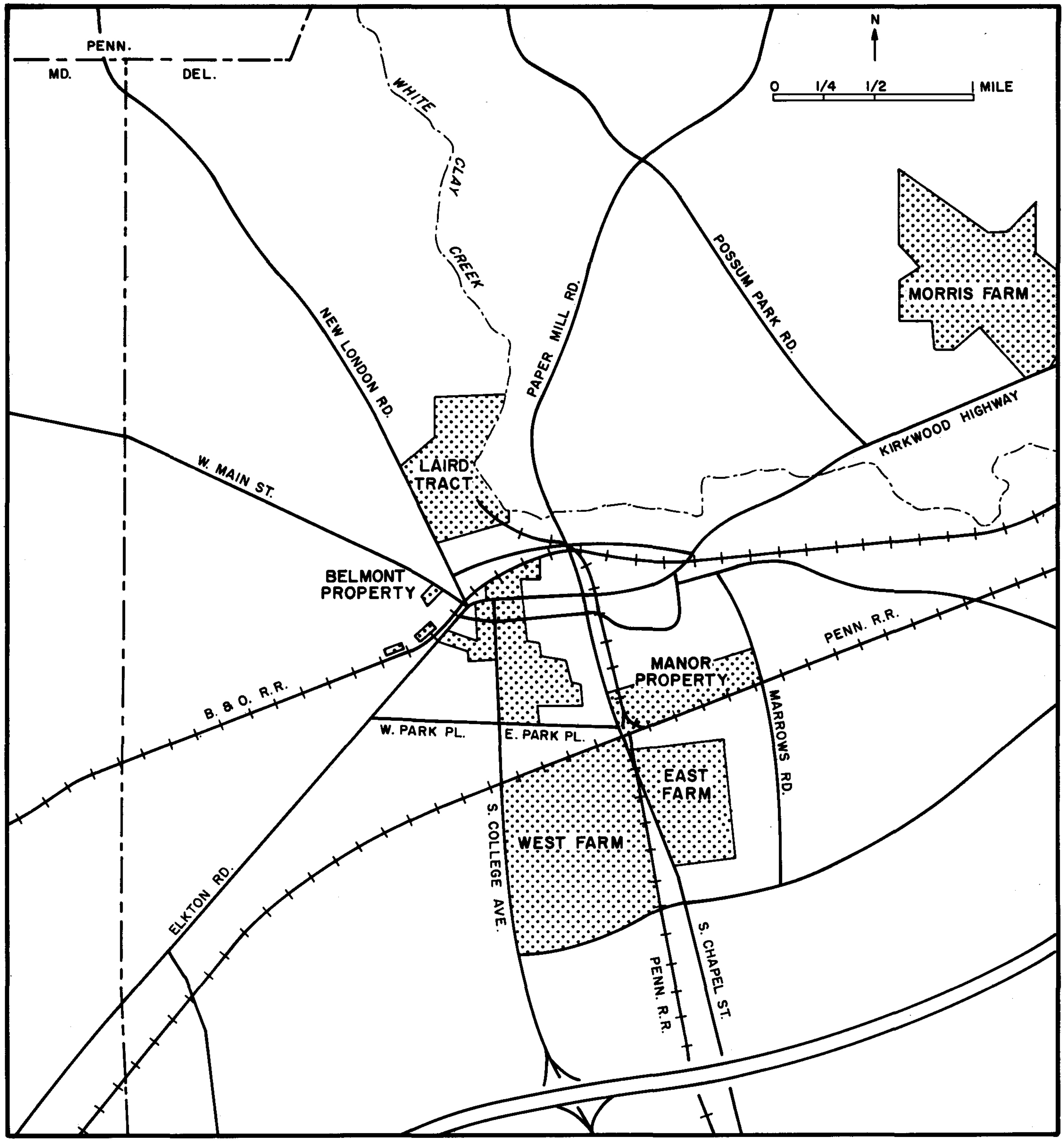


FIGURE 1. LOCATION OF UNIVERSITY LANDS IN THE NEWARK AREA (AFTER UNIVERSITY OF DELAWARE, 1968).

Methods

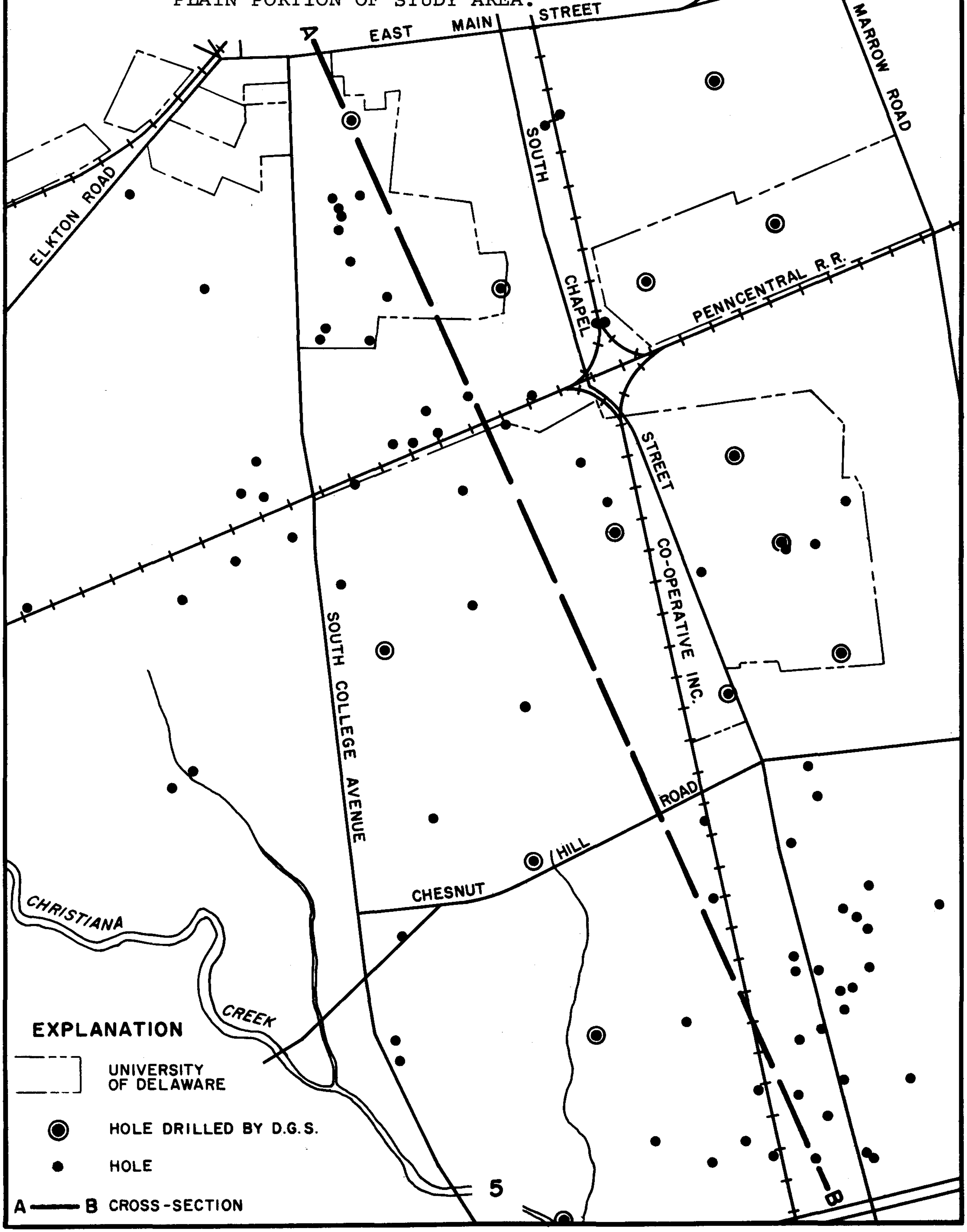
An understanding of the geology of an area is essential to the assessment of that area's ground-water potential, for the rock types and structures present constitute the basic framework in which ground water occurs. In unconsolidated sedimentary rocks exploration for ground-water sources, or aquifers, is directed toward the location of water-saturated sands. Such sands must have sufficient thickness and adequate permeability to support production wells large enough to be economically justified. In dense, crystalline rocks the search is designed to locate buried fracture zones that may permit the passage of large quantities of water to wells. As the City of Newark and the University properties straddle the Fall Zone and extend into the Appalachian Piedmont and the Atlantic Coastal Plain geologic provinces, both types of ground-water sources have been considered. The presence of two quite different provinces, both complex, compounds the problems of treating the involved geology and hydrology of the study area.

Existing well records, cores, samples, the results of previous work by the DGS, and private consultants provided a basis for exploration. Fourteen test holes totaling 1,405 feet were drilled by the DGS with the University drill rig assigned to the Water Resources Center. Five test wells totaling 1,831 feet were drilled in crystalline rock areas under contract with the Walton Corporation. One test hole in the Coastal Plain was drilled and cored by A. C. Schultes and Sons under contract with the City of Newark and with the direction of the DGS. Total geophysical logging in 15 test holes and test wells by the DGS was 4,899 feet. An additional 318 feet of logs were run by the U. S. Geological Survey (USGS). Two 12-hour and two 24-hour pump tests were made in the most promising wells. The locations of principal test holes and test wells are shown on Figures 2 and 3.

Previous Investigations

A study of the water resources of the Newark area by the DGS in cooperation with the USGS was published in 1954 (Groot and Rasmussen). That study outlined the basic ground-water sources still used by the City. Other reports of the DGS that have dealt, in part, with ground water in this area include those by Marine and

FIGURE 2. LOCATIONS OF TEST HOLES AND WELLS, COASTAL PLAIN PORTION OF STUDY AREA.



Rasmussen (1955), Rasmussen, et al. (1956), and Baker, et al. (1966). Several reports on ground water were prepared for the City of Newark by Geraghty and Miller, Consulting Ground-Water Geologists, during the period 1966-1970 and have guided the augmentation of the City's ground-water supply wells during that period.

ACKNOWLEDGMENTS

The City of Newark provided outstanding cooperation and made available its reports and records through the offices of Mr. Edward R. Stiff, City Manager, and Supervising Engineer Rex D. Gilmore. The cooperation of the drilling contractor, the Walton Corporation, and especially Messrs. Roy T. Walton and Joseph M. Holtzman was excellent.

The magnetometer employed in the surface geophysical surveys was loaned by Mr. John Allinghan of the U. S. Geological Survey, and the geophysical logging of one test hole was conducted by Richard Lucas of the USGS. Dr. Robert E. Sheridan of the Department of Geology, University of Delaware, and his students in the Elementary Geophysics course undertook parts of the magnetometer survey and its interpretation as a class project.

The Office of Plant Operations, University of Delaware, provided essential support throughout the study, particularly through the Ground, Security, and Plumbing Divisions. The University Planning Office provided maps, data, and coordination necessary to the program of exploration. Much of the exploratory drilling took place on the University Farm, where services and information were graciously provided by the Farm Manager and his staff.

Our gratitude extends also to each member of the University of Delaware Ground-Water Exploration Committee. As always, we are indebted to former Vice President George M. Worrilow for his wise counsel.

REGIONAL GEOLOGY

Delaware lies in two geologic provinces: the Appalachian Piedmont Province and the Atlantic Coastal

Plain Province. The Delaware portion of the Piedmont Province, about 100 square miles, contains very old igneous and metamorphic rocks of complex origin. The Coastal Plain rocks throughout Delaware are unconsolidated or partially consolidated gravels, sands, silts, and clays of much younger age which were deposited in marine and nonmarine environments. The study area lies in the Fall Zone and contains rock types characteristic of both provinces.

Piedmont Area

The Piedmont rocks were last studied in detail by Ward (1959). Spoljaric and Jordan (1966) compiled a generalized geologic map of the State. Piedmont rocks are assigned to a Early Paleozoic age and have been divided into the Glenarm Series (Knopf and Jonas, 1922) and the Wilmington Complex (Ward, 1959). The Glenarm Series is further subdivided into the Cockeysville Marble and the Wissahickon Formation. As is discussed later in this report, the Glenarm Series is of prime importance in the University study area. The Wilmington Complex has been subdivided into "amphibolites," "gabbros," and "banded gneisses" and some "granites" (Ward, 1959).

The Glenarm Series underlies the northwestern part of the Delaware Piedmont and the Wilmington Complex the eastern part. Both units are located north of the Coastal Plain sediments which complexly overlap the Piedmont rocks, roughly along the line of the Kirkwood Highway between Newark and Wilmington (Fall Zone). The Piedmont rocks continue under the Coastal Plain deposits south of the Fall Zone where they form the crystalline basement. In the Newark area these rocks are probably similar to the adjacent outcropping crystalline ones but farther to the south little is known about the nature of the basement rocks.

Iron Hill and Chestnut Hill, just south of Newark, may be outliers of Piedmont rock south of the main Piedmont area and are entirely surrounded by Coastal Plain sediments.

Coastal Plain Area

The sediments in the Coastal Plain dip toward the southeast. They form a wedge increasing in thickness from the edge of the Piedmont to the southeast where they are about 7,800 feet thick in southeastern Delaware. All rock units are included in this general discussion of the Coastal Plain for the sake of completeness and do not necessarily occur in the study area.

New Castle County contains the oldest sediments in the Coastal Plain. The Potomac Formation, a nonmarine Lower Cretaceous unit, consists generally of white, red, and purple variegated clays, silts, and some sands and comprises most of the Coastal Plain sediments in the Newark area.

After deposition of the Potomac Formation, sea level rose and encroached at least as far north as the Chesapeake and Delaware Canal area. The Canal area has been extensively studied (Pickett, 1970; Groot, et al., 1954) because it is the only place in Delaware where the Coastal Plain units are well-exposed. The marine formations (of Late Cretaceous age) are largely glauconitic sands and silts and are usually fossiliferous. These units extend only slightly north of the Canal area and are not found in the study area.

In southern New Castle County, Paleocene and Eocene greensands are present, indicating continuous marine conditions. Oligocene age sediments are absent indicating that the area was probably above sea level at that time. Sea level once again rose in Miocene time depositing blue-gray silts, clays, and sands in areas of present Sussex, Kent, and New Castle Counties.

There is a gap in the sedimentary record of about twelve million years from Miocene until Quaternary time, less than one million years ago. The Quaternary Period is subdivided into the Pleistocene (Ice Age) and Holocene (Recent) Epochs. The Pleistocene Epoch was a time of advances and retreats of continental glaciers accompanied by sea level changes that left a complex pattern of sands and gravels covering all of the older sediments. The Pleistocene sediments in Delaware are of both marine and nonmarine origin and are known as the Columbia Formation and Group.

The youngest sediments in the State are those of Holocene age, deposited after the retreat of the Ice Age glaciers about 8,000 years ago. These sediments are largely flood-plain and marsh deposits, such as those found in the White Clay, Christina, and Delaware River valleys.

The geologic units in the Newark area are the Potomac Formation, the Columbia Formation, and the Holocene sediments. Therefore, the detailed studies of the Coastal Plain geology and hydrology for this report are limited to these rocks.

PIEDMONT AREA

Occurrence of Ground Water in Crystalline Rocks

The hard rocks of the Piedmont generally yield smaller and unpredictable amounts of water than do the Coastal Plain rocks. This difference in the water-yield of the two areas results from the fact that the permeability of the crystalline rocks of the Piedmont is poor.

The Piedmont rocks, for this reason, are not generally thought of as aquifers, even though they might have moderate porosity. However, weathering and fracturing of such rocks can result in an increase of the permeability and porosity so that they can serve as dependable sources of water.

Rasmussen, et al. (1957) reports that the average yield for 141 Piedmont wells (predominantly drilled for industrial, municipal, or estate purposes) in rocks classified as granodiorite, schist, and gabbro, was 23 gallons per minute. The yields reported for these wells were probably obtained from short pump tests without considerable drawdown (indicating that the specific capacity of 0.92 gpm/foot of drawdown for 117 wells is exaggerated).

Random drilling, without geological studies of the area, can be very expensive if one is seeking more than just a domestic supply of water. The occurrence and availability of sufficient water for use by a community or industry in the Delaware Piedmont depend on the location of extensive fracture zones resulting from jointing and faulting of the rocks. It is also important that these fractures are free of impermeable clays, which can be a product of movement along faults or deep weathering, or both.

Geology of the Laird Tract

The Laird Tract is located entirely within the Delaware Piedmont and consists predominantly of metamorphic rocks, their weathering products, and, along White Clay Creek, a thin veneer of alluvial material (see Figure 3). The northern two-thirds of the property is underlain by the Wissahickon Formation (a biotite-quartz-plagioclase feldspar schist with migmatite zones) that strikes N70°E and dips 55-70° to the southeast. The schist is intruded conformably by medium- to coarse-grained pegmatites composed of muscovite, quartz, and pink potash-feldspar. The southern one-third of the Laird Tract is underlain by a fine- to medium-grained, dark greenish-black amphibolite striking N80°W and dipping at 67° to the south. The amphibolite is intruded conformably along the planes of foliation by a very coarse-grained pegmatite containing biotite, quartz, plagioclase, and minor potash-feldspar. These pegmatites show evidence of shearing.

All of the above rocks are fractured to some extent. The dominant joint directions in the northern two-thirds of the area are N-S and N57°W, dipping essentially vertically. The southern one-third of the area has joints trending N-S, N40°E, and N10°E. In the extreme southeastern portion on Bogy Run the pegmatites have been offset from one to five feet by small-scale reverse faults striking N10°E and dipping 27° to the west.

In addition to the field-observed joints and faults, inspection of aerial photos revealed mile-long lineations cutting across the general strike of the metamorphic rocks. These are interpreted as the surface traces of steeply inclined tabular fracture zones (Figure 4) essentially parallel to each other in two directions, N70°-80°W and N20°-30°W. The N70°-80°W zones are separated from each other by 600-800 feet and are apparently inclined to the south. The N20°-30°W fracture zones are separated by approximately 1,100 feet and seem to be inclined to the southwest. These parallel and regularly-spaced fracture zones are probably due to regional uplift with extensional forces opening the fracture zones. The areas between the fracture zones, although containing jointed rocks, are not as disturbed.

The N10°E small-scale reverse faults in the southeastern part of the area are probably related to the same uplift. The N10°E-trending reach of White Clay Creek bordering the northeastern part of the Laird Tract is undoubtedly controlled by similarly oriented faults and joints.

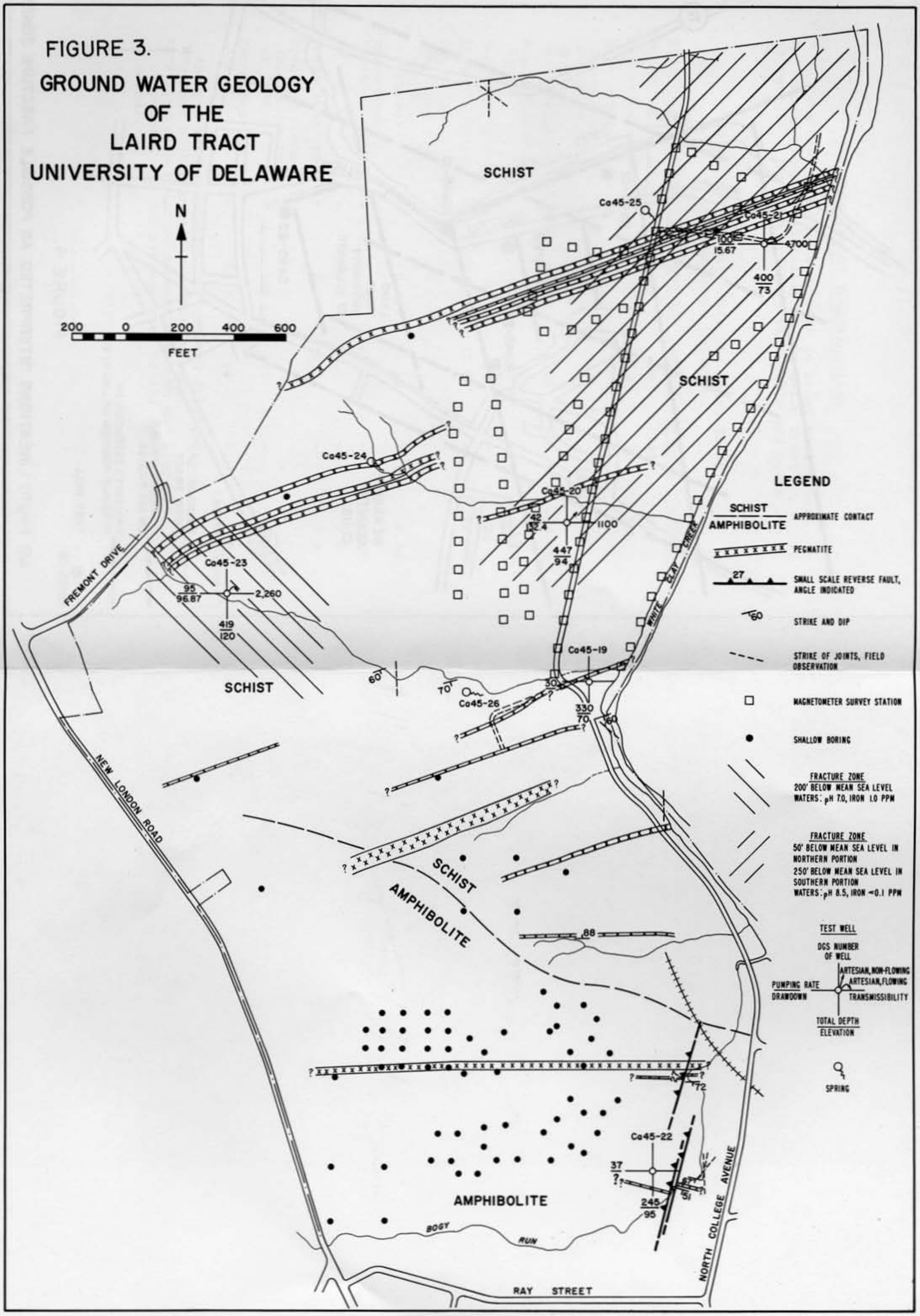


FIGURE 3.
GROUND WATER GEOLOGY OF THE LAIRD TRACT UNIVERSITY OF DELAWARE

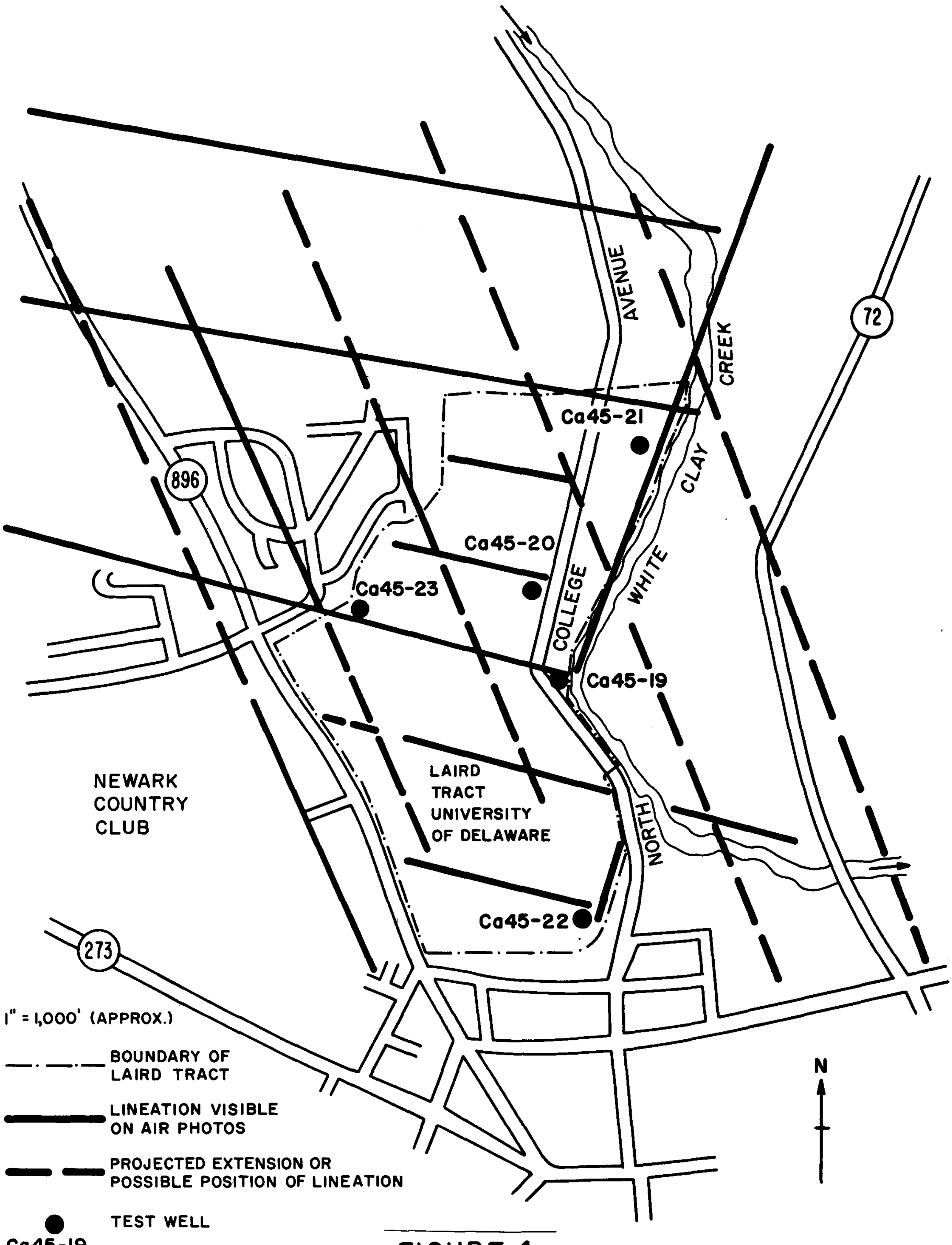


FIGURE 4.

AIR PHOTO LINEATIONS INTERPRETED AS POSSIBLE FRACTURE ZONES

Results of Investigations

Five test holes were drilled in order to evaluate the ground-water availability on the Laird Tract (Figure 3). The data on these test wells are given in Table 1.

Table 1. Test well data for Laird Tract, University of Delaware.

Test Well No.	Ca45-19	Ca45-20	Ca45-21	Ca45-22	Ca45-23
Depth (ft.)	320	447	400	245	419
Elevation (ft.)	70	94	73	95	120
Static Water Level (ft., relative to ground elevation)	-1.99	-9.80	+2.66	-10.97	+33.65
Pumping Rate (gpm)	30*	42**	100***	37*	95**
Duration (hrs.)	-	12	24	-	24
Drawdown (ft.)	-	132.40	15.67	-	96.87
Specific Capacity (gpm/ft. drawdown)	-	0.32	6.38	-	0.98
Transmissibility (gpd/ft.)	-	1,100	4,700	-	2,260
pH	-	8.5	8.5	-	7.0
Total Iron (ppm)	-	0.1	0.1	-	1.0
Specific Conduct. (micromhos/cm at 25°C.)	-	168	205	-	187
Temperature (°F.)	-	55.5	54	-	56

*Pumped with compressed air through drilling rod.
**Pumped with electric submersible pump.
***Pumped with electric submersible pump and also with compressed air (at average rate of 373 gpm for 12 hours).

Pump test data were analyzed employing the Theis curves and Jacob straight line method, but the transmissibility values obtained by the latter method are more consistent. The transmissibility values reported in Table 1 were obtained from recovery data for the pumped test well. Although many of the assumptions upon which the Theis nonequilibrium well formula (and its modification by Jacob) is based are not met by Piedmont aquifers, the values of T (transmissibility) are still indicative of the magnitude of yield and are probably of use in comparing the potential of different water-bearing fracture zones.

Specific capacity values for the flowing test wells, Ca45-21 and Ca45-23, were determined after additional well casing was added above ground so that the static water level could be measured. It was necessary, however, to start the pump tests of these wells with the extra lengths of casing removed. As a result, water was flowing from test well Ca45-21 at 7.5 gpm and from test well Ca45-23 at 37 gpm when the tests started.

The five test wells were drilled in order to verify the lineations observed on the aerial photographs as fracture zones and to see how the type of rock penetrated affected yield.

Test well Ca45-19 was drilled directly on top of a major N70°-80°W lineation (Figure 4) and encountered schist, migmatite zones, and small pegmatites. The yield was only 30 gpm. Apparently, however, this lineation was not related to the southerly-dipping fracture zones previously mentioned. These latter zones were probably too deep to be intersected by this well.

Test well Ca45-20 was drilled to test the nature of a N70°-80°W lineation that is located a short distance north of the well (Figure 4). A magnetometer survey also indicated that conditions were favorable for the occurrence of ground water. It is believed that zones of relative low magnetic intensity to the north of the test well site represent a fracture zone inclined to the south. Water of appreciable quantity was not encountered in this test well above 342 feet and no additional water was found upon drilling to 447 feet. Until test well Ca45-21 was drilled and pumped it was not known that test well Ca45-20 was located on the edge of a larger fracture zone. For that reason few fractures and little water are present. A 12-hour pump test on well Ca45-20 confirmed that an impervious boundary exists nearby, probably to the south and southwest. Because of rapid drawdown during the pump test, the rate of pumping was held at 42 gpm. Development and pumping recommendations of this test well are to be found in a later section of this report.

Test well Ca45-21 was drilled near the intersection of three lineations (N10°E, N70°-80°W, and N20°-30°W) on the flood plain of White Clay Creek. The magnetometer survey showed that the rocks beneath and to the north of well Ca45-21 exhibit a relative magnetic low, possibly indicative of a fracture zone. Extensive fracturing was encountered in the depth interval 126-237 feet and at other depths down to 400 feet. Although increasing water yield with increasing depth in the 126-237 foot interval was observed, it was impossible to ascertain whether the deeper fractures also yielded water. The available amount of compressed air used for pumping was not adequate to handle the large amount of water entering the test well from the upper fractures alone. Cuttings from the test well were often large fragments of schist with parallel joint surfaces indicating closely spaced fracturing (1-2 inches apart). The existence of a major fracture zone beneath that portion of White Clay Creek is further suggested by the mutual response of test wells Ca45-20 and Ca45-21 when one or the other is pumped. Test well Ca45-21 is located in the more permeable part of the fracture zone as is indicated by its higher specific capacity (6.38 vs. 0.32 gpm/ft. of drawdown) and higher transmissibility (4,700 vs. 1,100 gpd/ft.). The higher yields in test well Ca45-21 also seem to be attributable to the occurrence of a greater number of pegmatites which are more shattered by the cross-cutting fracture zones. Both test well Ca45-21 and test well Ca45-20 are artesian and the first flows at 7.5 gpm. A 24-hour pump test at 100 gpm on test well Ca45-21 indicates a recharge boundary nearby, probably White Clay Creek.

Test well Ca45-22 was drilled in the southern portion of the study area for three reasons: (1) to evaluate the potential of the highly-fractured amphibolite as an aquifer, (2) Bogy Run appears on the aerial photographs to occupy a fairly long lineation, and (3) the displacement of pegmatites by small-scale reverse faults striking N10°E was thought to be evidence for possible deep fracturing in the amphibolite. Although 37 gpm was obtained from fractures in this well, it is felt that the amphibolite becomes "tighter" with greater depth and that exploration in the areas of Wissahickon Schist would be more rewarding.

Test well Ca45-23 was drilled to test the N70°-80°W lineation that passes through test well Ca45-19. The main fracture zone was reached at a depth of 316 feet. This fracture is probably related to other lineations to the north which are inclined to the south as fracture zones. Shattered pegmatites contribute much of the yield although a large portion does come from the fractured schist. As in test well Ca45-21 many fragments of schist with closely-spaced parallel joint surfaces were obtained in the cuttings. Test well Ca45-23 flows at land surface under artesian pressure at 37 gpm. The pump test on this test well indicates that an impervious boundary, perhaps a clayey portion of the fracture zone or the amphibolite to the south, exists nearby.

Neither test well Ca45-20 nor test well Ca45-21 responded to pumping of test well Ca45-23 and it is concluded that the waters come from separate fracture zones. Further evidence for this is that the water from Ca45-23 has a pH of 7.0 and an iron content of 1.0 ppm (parts per million), whereas Ca45-20 and Ca45-21 have a pH of 8.5 and an iron content of less than 0.1 ppm. Development and pumping recommendations for this test well are to be found in a later section of this report.

As the pH of White Clay Creek is also 8.5, the iron content also less than 0.1 ppm, and the specific conductance (192 micromhos/cm at 25° C.) comparable to that of the waters of test wells Ca45-20 and Ca45-21, there is little doubt that the fracture zone tapped by these two test wells comes to the surface either to the north or northeast of the area in the bed of White Clay Creek and is recharged by the stream. This is also evidenced by the recharge boundary noted during the pump test of test well Ca45-21.

The chemical quality and flow data given in Table 2 were also obtained for three springs in the area. The low pH, low specific conductance, and lower temperatures (recharge during cold winter months) indicate that these springs have their sources at shallow depths and are unrelated to the fracture zones. Thus, there is no benefit to drilling near these springs for additional water.

Table 2. Chemical quality of springs on the Laird Tract, University of Delaware.

Spring No.	Ca45-24	Ca45-25	Ca45-26
pH	5.0	5.5	5.0
Total Iron (ppm)	<0.1	<0.1	<0.1
Sp. Cond. (micromhos)	162	87	93
Temp. (°F)	46.6	50	48
Flow (gpm)	1	3-5	3-5

COASTAL PLAIN AREA

Geology

Crystalline Basement Complex

Figure 2 shows the coastal plain area considered in this study. The oldest rocks in the study area are those of the crystalline basement complex and form the base upon which the younger sedimentary rocks were deposited.

Very little is known about these basement rocks for two main reasons: (1) because of their crystalline nature they were thought to be of little importance as a possible source of ground water and consequently not drilled, and (2) drilling through such rocks is expensive and often time consuming.

The surface of the basement complex was believed to be continuous although the existence of faults had been suspected by Groot and Rasmussen (1954). This study has shown that the surface of the basement is indeed broken by faults (Figure 5). These faults have produced small horst-graben structures that stand out quite prominently both in the cross section (Figure 6) and on the structural map of the basement (Figure 5). Most of the faults were produced by vertical displacements. The largest displacement exceeds 100 feet and can be observed along the northeastern margin of Chestnut Hill. A displacement of nearly the same magnitude can also be seen along the north-south trending fault in the City of Newark's southern well field.

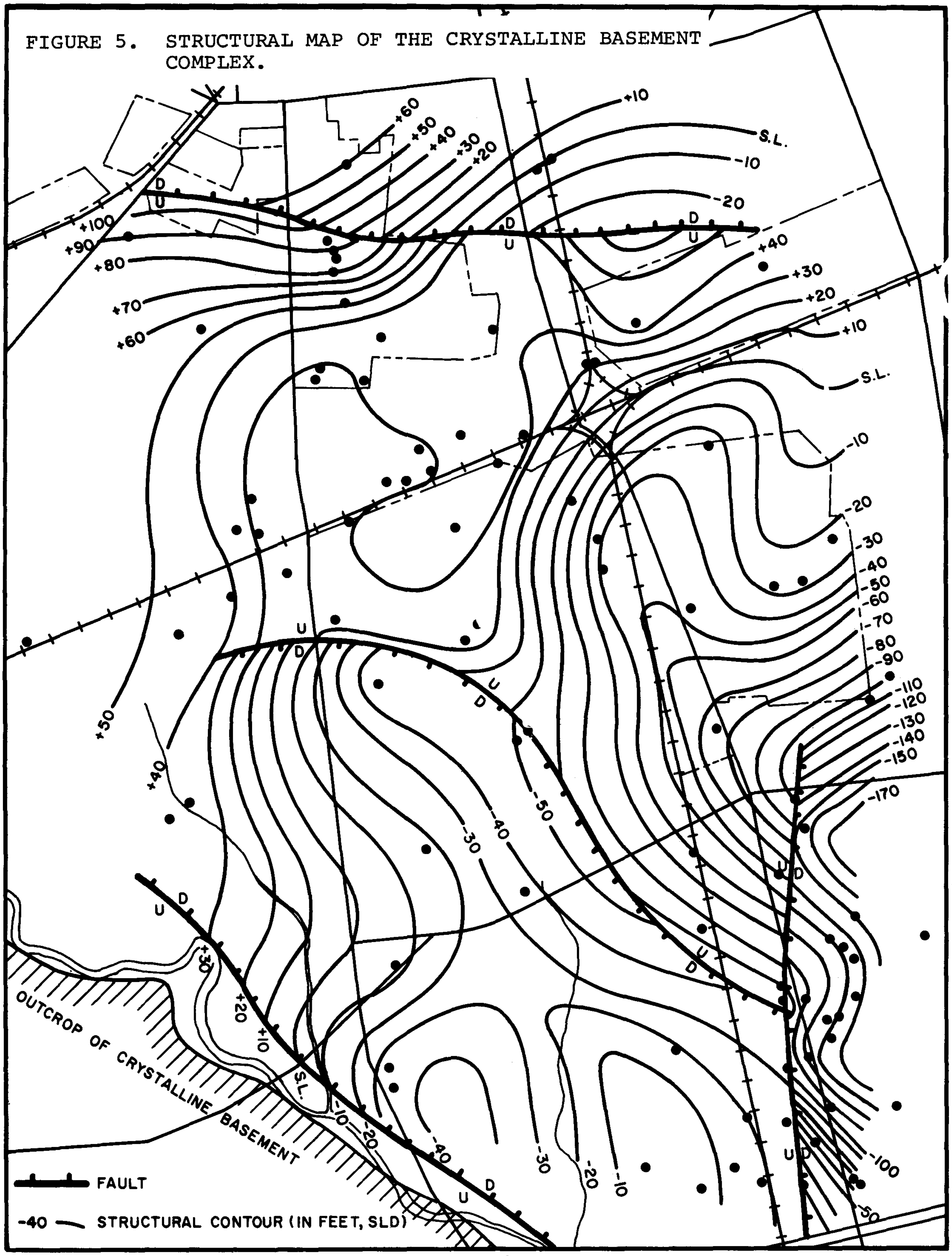


FIGURE 5. STRUCTURAL MAP OF THE CRYSTALLINE BASEMENT COMPLEX.

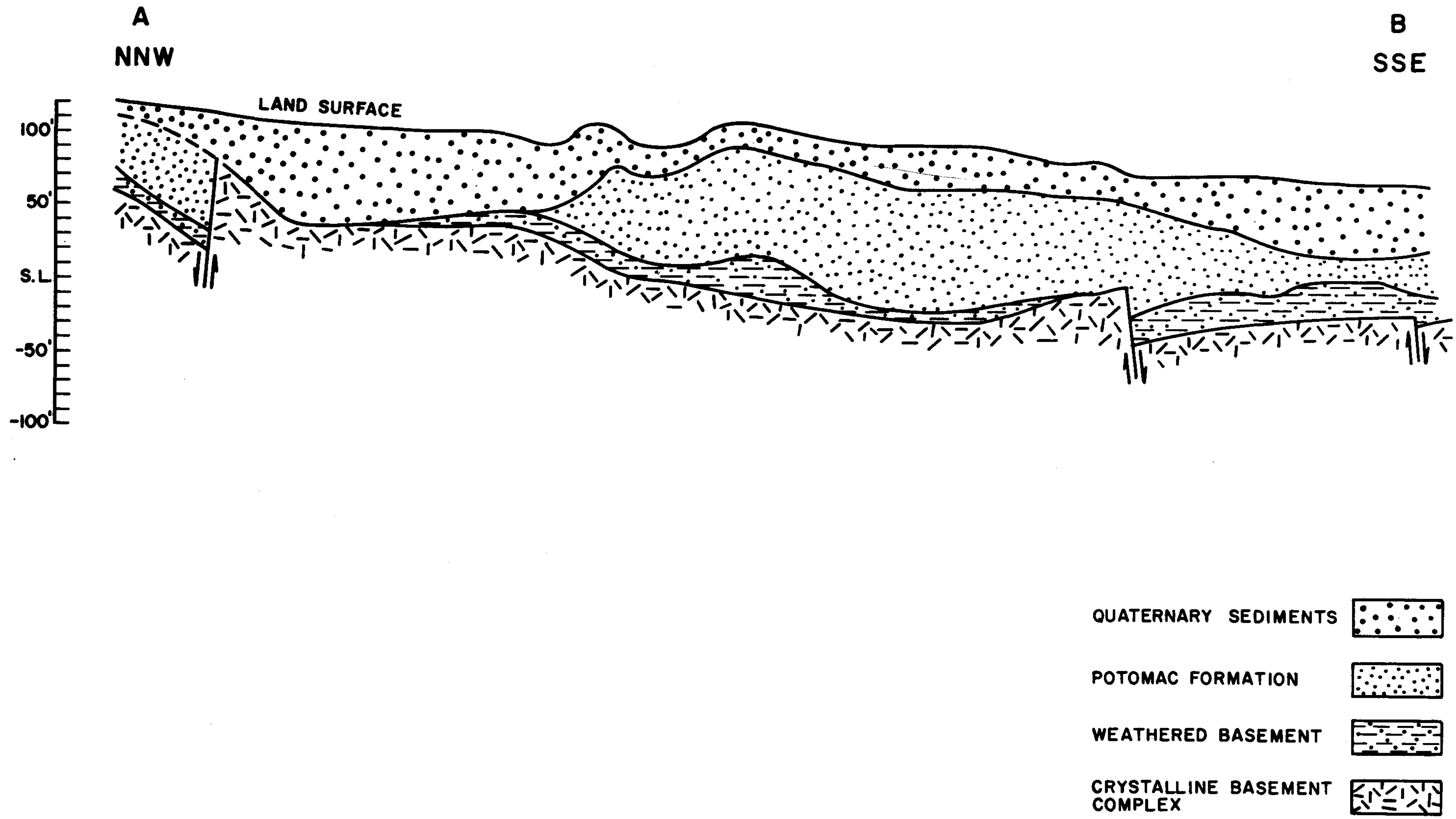


FIGURE 6. GEOLOGIC CROSS SECTION.

The east-west fault in the northern part of the study area, just south of Main Street, may have been formed by lateral rather than vertical displacement as suggested by a smooth transition of the structural contours across the fault line. A lateral movement of several hundred yards could account for the structural relationships observed on both sides of the fault.

Although data are scarce, they do suggest that the fault planes are quite steep. However, the depth and age of the faulting are unknown.

Weathered Crystalline Basement Complex

Crystalline basement rocks under the Coastal Plain are everywhere overlain by their weathered products. This material is composed mostly of tight, varicolored clays and very clayey, poorly sorted sands and silts. Fragments and boulders of partly decomposed original rocks are also frequently encountered. The thickness of the weathered material varies from place to place (Figure 7) and this variability is probably due to the composition of the original crystalline rocks, geochemical conditions of weathering, and, possibly, to contemporaneous slumping of such materials on steep slopes such as on the northeastern margin of Chestnut Hill. For these reasons no relationship between the location of faults and the thickness of the weathered material has been recognized.

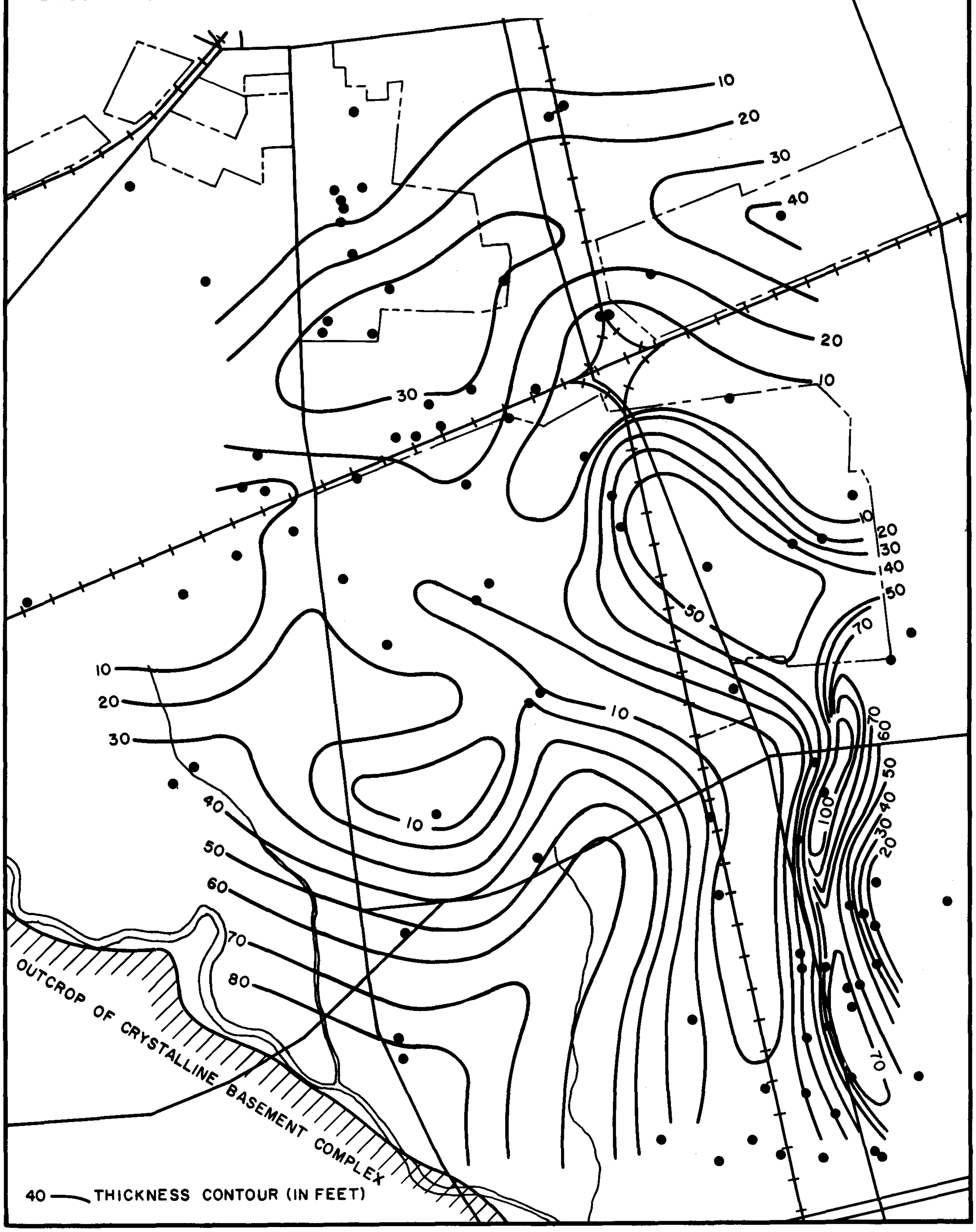
The weathered material is usually relatively impermeable due to its clayey composition and thus is of no importance as a possible source of ground water. On the contrary, this material is often detrimental because it may impede the recharge of ground water from the Coastal Plain sediments above into the fractured zones of the crystalline basement complex below.

Potomac Formation

In the present study area the Potomac Formation is composed of varicolored, lignitic clays and silts, white and gray, fine- to medium-grained sands, and some gravels.

Groot (1955) made an extensive study of the Potomac sediments and was able to subdivide them into two zones on the basis of their heavy mineral composition; the lower zone distinguished by an abundance of the mineral

FIGURE 7. THICKNESS OF WEATHERED BASEMENT COMPLEX.



staurolite, and the upper one characterized by a tourmaline-zircon-rutile suite. Only the lower zone is present in the study area.

The Potomac sediments were deposited in ancient stream channels, on banks, flood plains, and similar environments. It is, however, extremely difficult to recognize these various environments, particularly in the subsurface. A detailed study of these deposits in a small area west of Delaware City (Spoljaric, 1967b) has demonstrated that the ancient streams that deposited these sediments were characterized by fluctuating water and sediment discharges, and by frequent shifting of their courses.

In the Newark area the composition of the Potomac Formation is dominated by clays and silts (Figure 8). The largest accumulation of such sediments is found in the northern part of the area where it attains a thickness in excess of 90 feet.

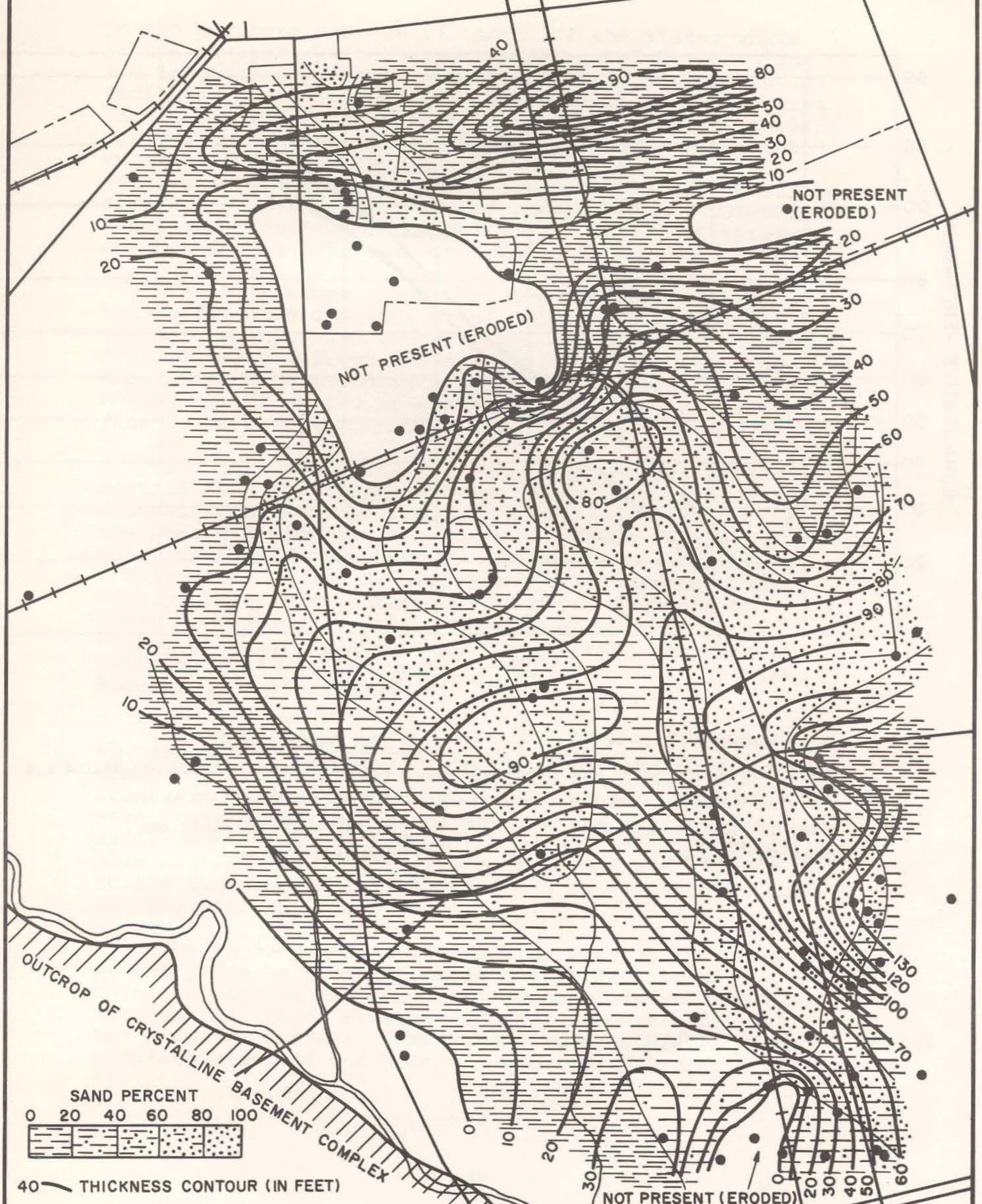
The sands are fine- to medium-grained, often poorly sorted, and contain about 5 percent of clayey and silty matrix (Figure 9 and Groot, 1955). They are concentrated in the central and southeastern part of the area, and their thickness in places reaches more than 90 feet. The form and areal extent of the sand bodies suggest that the streams that transported these sediments entered the area both from the north and from the east. Groot (1955) concluded that these deposits were derived from source areas in the Piedmont portion of the Appalachian Mountain System.

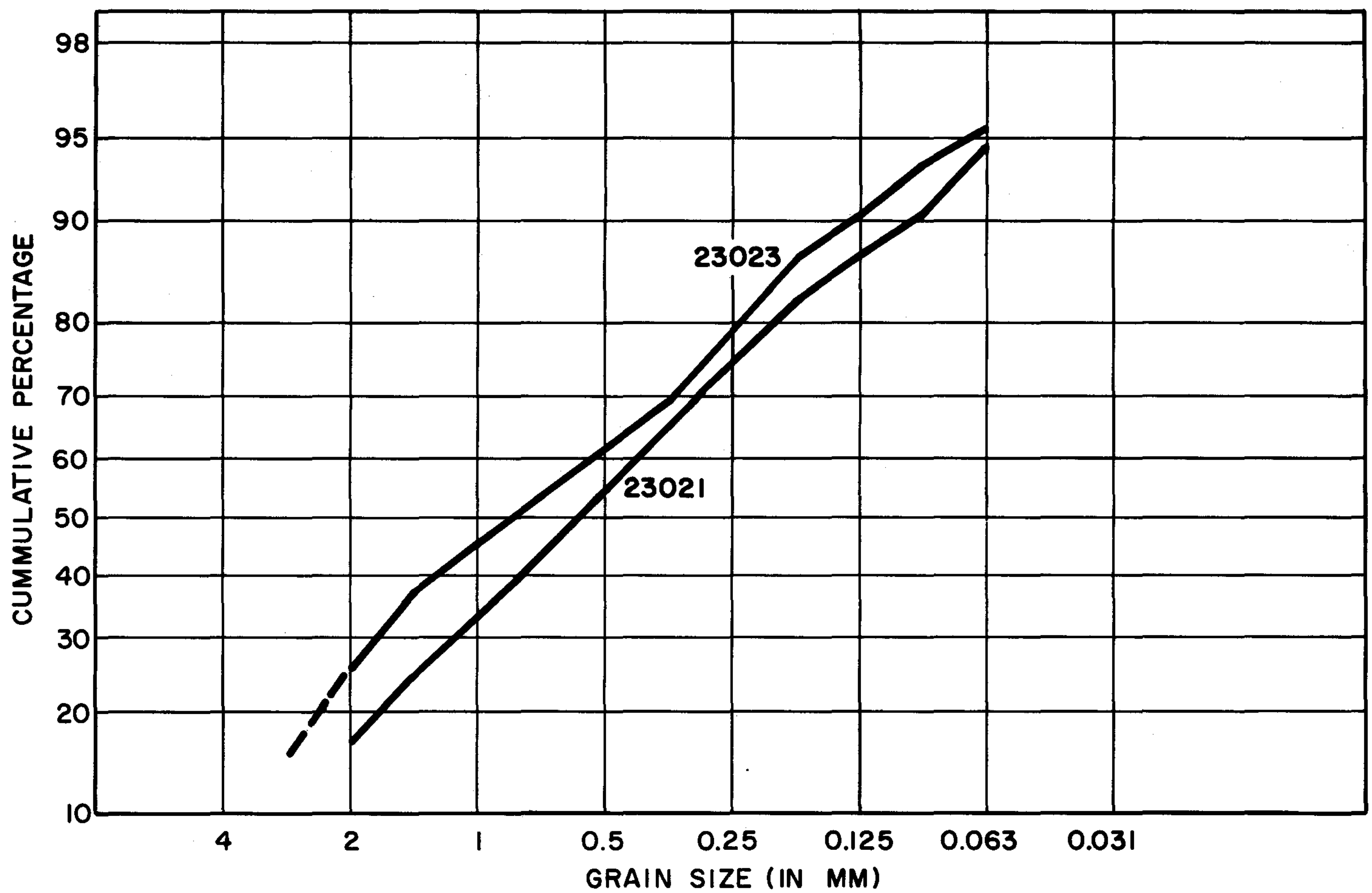
The deposition of the Potomac Formation seems to have been strongly controlled by the configuration of the underlying basement surface. For example, in the northern part of the area the east-west trending fault has produced a depression on its northern side which acted as a catchment area for the thick accumulation of Potomac clays.

Quaternary Sediments

Quaternary sediments form a surficial cover over the older rocks in the study area. They are composed of yellow and brown clays, silts, sand, and gravels and include the Columbia Formation and later Holocene materials. Statewide study of these sediments by Jordan (1964) has shown that they are of fluvial origin

FIGURE 8. LITHOFACIES MAP OF THE POTOMAC FORMATION.





WELL NUMBER: Db12-42
SAMPLE NUMBER: 23021 (80' BELOW L.S.)
MEDIAN DIAMETER: 0.59 MM
MEAN DIAMETER: 0.58 MM
SORTING: 0.28 MM

WELL NUMBER: Db12-42
SAMPLE NUMBER: 23023 (90' BELOW L.S.)
MEDIAN DIAMETER: 0.83 MM
MEAN DIAMETER: 0.77 MM
SORTING: 0.27 MM

FIGURE 9. SIZE ANALYSES OF POTOMAC SANDS.

in the northern and central parts of the State, while in the southern part they are represented by shoreline and lagoonal deposits. A detailed study of the fluvial facies of these sediments in the Middletown-Odessa area (Spoljaric and Woodruff, 1970) revealed that the ancient streams that transported and deposited these sediments were shallow, usually less than 1/2 mile wide, and frequently shifted their courses within a braided stream system. However, north of the Chesapeake and Delaware Canal these ancient streams formed a system of straight and meandering channels (Spoljaric, 1967a).

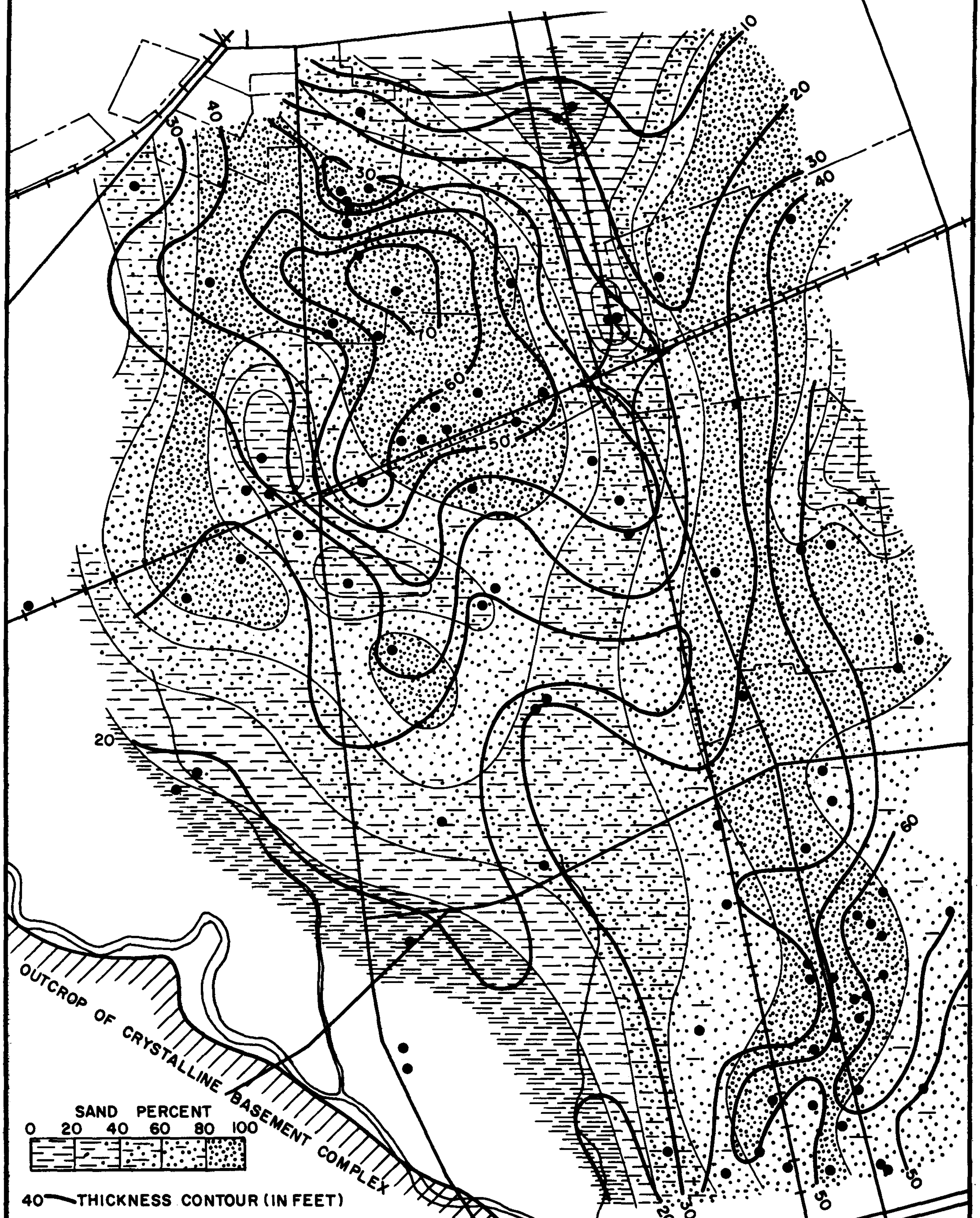
In the present study area the Quaternary sand bodies form two distinct areal units; one is located in the northwestern and central part of the area, and the other closely follows the eastern margin of the study area from north to south (Figure 10). These two sand bodies are separated by a north-south trending zone of fine Quaternary sediments.

The form and areal extent of the northwestern-central sand body suggests that these sediments were brought into the area from the northwest, probably from the nearby Piedmont. The sands are fresh-looking, quite coarse, poorly sorted, micaceous, and contain a considerable amount of clayey and silty matrix. They were probably transported only a short distance to their depositional sites. Maps drawn on the distribution of these sediments show a distinct fan-shaped pattern. The City of Newark's northern well field is located in these sediments.

The other sand body, along the eastern margin of the area, has a shoestring form characteristic of typical fluvial sedimentary bodies. The shape and areal extent of this body show that these sediments were transported into the area from the northeast and east. The sands are medium to coarse, poorly sorted, have little clayey and silty matrix, and are similar to the Quaternary fluvial sediments of Pleistocene age elsewhere in the State.

The streams that deposited the Quaternary sediments probably had high competencies and velocities as evidenced by the abundance of coarse sands and gravels. In addition, these streams cut their channels deep into the underlying older rocks and in several places have completely eroded the Potomac sediments (Figures 6 and 8).

FIGURE 10. LITHOFACIES MAP OF THE QUATERNARY SEDIMENTS.



Hydrology

General Ground-Water Availability

The recharge for local ground-water supplies comes directly from rain falling in the northern New Castle area. Tempting as it may be to speculate, there are no hydrologic or geologic connections with other sources far to the north (except by way of surface streams). Thus, the water resources in the Newark area must be managed as dictated by the local hydrologic and geologic setting.

The average rainfall for northern Delaware is about 44 inches per year based on the period 1931-60. Total rainfall as measured at the University of Delaware was 56.3 inches in 1969 and 38.4 inches in 1970. The proportion of this water available for ground-water recharge within a given area can be approximately calculated. This is usually helpful in order to arrive at the general magnitude of water that may be available.

In a normal rainfall of 44 inches per year, about 40% to 60% is lost to evaporation and transpiration and about 10% is lost by direct overland flow to streams. This leaves about 50% that may reach the water table. However, of this 50% only about 25% is available to wells. The remaining losses are due to seepage from the water table to maintain the base flow of streams, ground-water evapotranspiration, and seepage to oceans. Thus, in northern Delaware about 11 inches of precipitation in a year of normal rainfall is available for recharge to aquifers. The amount available is even less in a drought period such as occurred from 1960-1966. The University lands in the Newark area total about 1,082 acres (University Planning Office) or 1.62 square miles. This would give a total available water yield of about 974 acre feet or $3x10^8$ gallons per year. On an average this would be about 800,000 gallons per day available or about 550 gallons per minute. This should not be taken as an inviolable figure but only as a rough approximation of what could be expected. Some of this available ground water is already being used by withdrawals on adjacent lands by the City of Newark's north and south well fields. It can be shown that the effect of the north well field in particular extends into University lands.

Present water use by the University is not known with certainty. However, Miller (1970) points out that the 15,000 regular student population expected in 1976-77 would use an additional 604,000 gallons per day over that of present use. Thus, the ground-water capability of University lands, if fully developed, might be enough to supply the increased demands through about 1977. This assumes that there would be no periods of extended drought.

Sources of Ground Water in the Newark Area

As can be seen in the preceding section on geology, the water-yielding capabilities of most sediments are determined initially by the environment in which they were formed. In the Coastal Plain portion of the Newark area the requirements for a satisfactory aquifer are generally only partially fulfilled by the two major rock units present: the sands of the Potomac Formation and the sands and gravels of the Quaternary deposits. Sediment type in the Potomac Formation is not always persistent and individual beds are difficult to trace laterally. As seen earlier in this report, sands often are stringers or lenses rather than sheet-like deposits. While such sands may yield water for a short period of time, they lack the areal extent necessary to support wells of high yield. Often sands of the Potomac Formation are fine-grained and well development is difficult. Records in the Delaware Geological Survey's files show that many well development attempts in these fine sands ended in failure.

Sundstrom and others (1967) were able to subdivide the Potomac Formation in the Chesapeake and Delaware Canal area into an upper and a lower hydrologic zone. The lower zone is the only one extending into the present study area although the distinctions become somewhat unclear.

Potomac sands are generally separated from overlying Pleistocene sands by intervening clay or silts. In such cases the water in the Potomac sands is usually under artesian pressure, that is, the water level in the aquifer rises above the top of the aquifer. In the Newark area, artesian pressures are not great and water levels are generally low with respect to the top of sands within the Potomac.

The Quaternary deposits, which generally rest upon the other rock types in the area, usually is the local water-table aquifer. Water in Quaternary sands is thus under barometric pressure only and does not rise above the top of the aquifer. The total thickness of the deposits rarely exceeds 40 feet and the saturated thickness is usually not enough to sustain high-yielding production wells. Two exceptions to this situation are (1) when Quaternary sands are in direct vertical contact with underlying Potomac sands and (2) where Quaternary sands have been channeled into the Potomac Formation and are locally much thicker than usual. In both cases the total saturated thickness is generally higher than average and wells yielding up to several hundred gallons per minute may be obtained. Probably the most important function of the Quaternary deposits is that they provide vertical recharge to the underlying Potomac sands. Thus, over short time periods these two formations can be treated separately but over periods of months they should be considered as a single leaky aquifer. Development of one formation will eventually affect the development of the other.

Results of Investigations

Fifteen test holes were drilled in the Coastal Plain portion of the University lands and geophysical logs were run in most of these (Figure 2). The objectives of the Coastal Plain portion of the study were (1) to determine the thickness and water-bearing characteristics of any sands that might be present, (2) determine the depth to basement rock, (3) improve and expand control points and thus provide better geologic correlation. The results of individual areas are presented below.

Manor Tract

Two test holes were drilled on the Manor Tract, one near each end of the property (east-west). The Columbia Formation here is between 40 and 45 feet thick and lies almost directly upon weathered basement. The Potomac Formation is thus very thin and probably absent in the northern half of the tract. The water table at time of drilling was about 10 feet below the land surface, which gives a saturated thickness of about 30 feet. A system of shallow wells, perhaps even drive points, may be a possibility at this location. The construction of large yielding wells is not feasible because of the relatively low saturated thickness. However, up to 75 gpm might be obtained from a number of carefully spaced small yielding wells. A test well and pump test are necessary to accurately define the yield possibilities and to work out the well spacing.

Webb Farm

Three test holes were initially drilled on this tract by the Delaware Geological Survey and later a fourth hole was drilled by A. C. Schultes and Sons under contract with the City of Newark. Sands in the first three holes were encountered at various depths. At the northern end of the tract, in hole Cb51-49, the electric log showed what may be water-bearing sand from about 60 to 70 feet below land surface. It is very possible, however, that this material may be weathered basement fragments in a clayey matrix of weathered basement and as such would not be water-bearing. No reliable sample returns were obtained from auger drilling at this depth in this particular hole. A higher sand occurs at the same location from about 32 to 38 feet below land surface and a core sample shows this sand to be suitable for screening. However, the sand is not thick enough to support a high yielding well. The area may be suitable for construction of a low yielding well (50 gpm or under) but the cost of constructing a pipeline to this location and the treatment facilities must be weighed against the low yield to be expected.

Much of the first 10 to 20 feet of Pleistocene sands that might normally be expected have been eroded at this location and replaced by Holocene stream silt. Thus, the effective saturated thickness has been reduced.

Test hole Cb51-41 was drilled near the central portion of the Webb Farm and showed that the Columbia Formation may be up to 50 feet thick. However, much of the formation is silty, which reduces the overall water-yielding properties of the sediment. Also, the low water table, about 30 feet below land surface, gives a saturated thickness of only 15 to 20 feet. Thus, the location is suitable for only a low-yielding well and is not recommended for development at present.

The thickest section of Coastal Plain sediments occurs in the southern part of the property near Brookside. The combined thickness of Pleistocene and Potomac Formations appears to be about 150 feet. The

Pleistocene sediments are about 40 to 50 feet thick and seem to be an extension of a paleochannel known to occur farther to the south. Again, considerable fine material is present which would give difficulties in well development. Several relatively thin sand layers occur in the underlying Potomac Formation at various depths and the thickest one seems to be from 125 feet to 135 feet below land surface at the location of well Db12-42. A core sample showed this sand to be quite coarse and suitable for screening. Any well development in this general area, however, would be affected by the presence of a production well in Brookside about 1,100 feet away. Only a test well would accurately determine what might be expected in the way of production and the degree of well interference.

The fourth test hole on the Webb Farm (Db12-43) was drilled by the City of Newark after consultation with the University and the Delaware Geological Survey. The site chosen was due partly to readily available electric power and a main water line. Although three promising zones were indicated on the electric log of this test hole, subsequent side-wall cores showed all three zones to be unfavorable for screening. The most favorable indication on the electric log, from 115 to 123 feet, was shown by the core sample to be coarse fragments of weathered basement in a clayey matrix and thus not water yielding. Two higher zones, from 86 to 89 feet and from 105 to 109 feet, also proved too clayey for screening.

West Farm

Four test holes (Cb51-43, Da15-17, Db11-51, and Db11-52) were augered on the West Farm east of Chapel Street Extension and west of Route 896 (Figure 2). All four locations are unsuitable for immediate groundwater withdrawals. The Columbia Formation in every case is thin and the Potomac sands are very fine and would be extremely difficult to develop. These fine Potomac sands may have possibilities for well development under expert guidance and advice such as available from a commercial well screen company. At present, local drillers have had little success with development and have abandoned them in favor of coarser sands. Yet, these fine sands represent potential water supply and should be investigated for future well possibilities. Such sands occurred from about 40 to 60 feet below land surface in the south end of the property, just south of the University of Delaware stadium and from about 50 to

80 feet below land surface in the northeast section near the University weather station.

An auger hole just north of Agricultural Hall revealed poorly sorted sand to very large gravel and some cobbles from the land surface to about 33 feet. However, the material was entirely dry and later measurements placed the water table at around 40 feet below land surface. The low saturated thickness thus rules out any well development at this location. It should be noted that an earlier report to the University (Miller, 1970) pointed out that ground-water recharge was a possibility in some areas. The dry sand indicated in the upper 30 feet of this latter hole has distinct possibilities for ground-water recharge. Thus, the site should be considered for recharging purposes in the overall water program.

Main Campus

Two test holes were augered on the main campus, one near DuPont Hall (Ca55-53) and the other just south of the Gilbert Dormitory complex (Cb51-42). Neither of these locations showed any promise of ground-water production. Previous work near Robinson Hall and work recently completed near the Morris Library for another project also indicates that the main campus has little ground-water potential.

CONCLUSIONS

Piedmont Investigations

Selection of Drilling Sites

It is concluded that fracture zones do exist and can be identified on aerial photographs as long, essentially straight, and often parallel lineations. Up to about 500 gpm on a long-term basis could probably be developed from the Laird Tract in properly located wells. Recharge to the fracture zones apparently takes place along the surface traces or lineations. The reason for the hydrologically separate fracture zones encountered by test well Ca45-23 and test wells Ca45-20 and Ca45-21 is not known at the present time. This may be due to clay resulting from deep weathering of fault movement filling in the fracture zone and preventing migration of ground water from one area to another.

The use of a magnetometer to define areas of relative magnetic highs and lows appears to be of value in selecting sites for test wells if a large enough area can be studied. The chemical characteristics of the waters in the fracture zones should be considered in determining the nature of ground-water occurrence in the Delaware Piedmont. Most successful wells drilled in the Piedmont on fracture zones will have yields similar to test well Ca45-23 rather than test wells Ca45-20 and Ca45-21 unless they are drilled on the flood plains where there is a chance of induced recharge from the stream. Yields also seem to increase in areas where pegmatites are abundant.

Well Development

Proper pump selection and depth of pump setting depend on an accurate determination of predicted future drawdown. This prediction is often made by extending the straight line plot of drawdown vs. time obtained from a pump test. However, since the hydrology of fractured rocks over a short time period may be different from that of the homogeneous aquifers upon which pump test analyses are based, considerable caution must be used. The limited 12-hour or 24-hour tests conducted on Piedmont wells do not usually yield enough information to predict the effect of long-term pumping. Additional impervious boundaries can affect drawdown long after initial well development and pumping. Therefore, any predictions of future drawdown must not necessarily be considered as exact.

Three of the test wells, Ca45-20, Ca45-21, and Ca45-23, appear suitable for development. Their recommended development and rates of pumping are discussed under "Recommendations."

Coastal Plain Investigations

The study did not show any locations within University property that were suitable for development of high yielding wells (about 100 gpm or over). Low yielding wells have a total potential of about 175 gpm and could be developed at the Webb Farm, the Manor Tract, and the West Farm, if the economics can be justified. Well development and spacing between wells will be critical. The fine sands beneath the south portion of the University West Farm present a particularly difficult development problem. However, technology exists to overcome these problems when it is deemed economical.

Ground-water recharge again seems feasible in certain areas and should be made a part of future development plans.

RECOMMENDATIONS

The following recommendations are made as a result of the completed assessment of the ground-water potential beneath University Lands:

1. On the Laird Tract test wells Ca45-20, Ca45-21, and Ca45-23 should be converted to production wells by reaming to a diameter of 8-10 inches. Well casing should be set and properly grouted to prevent contamination (in accordance with the regulations of the Water and Air Resources Commission of the State of Delaware). Any well, pump, and treatment facilities at the site of test well Ca45-21 should be so constructed as to prevent contamination from flood waters and backed up nearby sewers when White Clay Creek is in flood. Nearby sewer lines at Ca45-23 also warrant special caution in well construction.

   Table 3 of pumping recommendations takes into account the present unpredictable effects of the nature of fracture zones upon long-term yield by assuming that the recommended long-term pumping rate should be at least 25 percent less than the pumping rate determined from the time-drawdown curve.

Table 3. Predicted performance of Laird Tract wells.

Test Well No.	Ca45-20	Ca45-21	Ca45-23
Pumping Rate (gpm)	65	300	145
Drawdown (feet)	290	77	281
Time since start of pumping (days)	70	700	700

These rates of pumping should serve only to indicate the magnitude of the yield to be expected. Final pumping rates should be determined after the test wells have been reamed to 8-10 inches in diameter, casing set, and the well properly grouted.

All production wells should be monitored and fitted with an automatic pump cut-off to prevent the water level dropping to the pump level or the level at which the fracture zones occur (342 feet in Ca45-20, 126 feet in Ca45-21, and 316 feet in Ca45-23).

2. Test well Ca45-22 in the Laird Tract should be properly cased and grouted so that it can serve as a utility well (grounds maintenance use). It should not be tied into the public water supply. A yield of at least 35 gpm can be expected from this well.

3. Production of ground water from the Laird Tract must allow for rest periods of individual wells. The length of each rest period would have to be determined after development and initial pumping and then should be integrated into the overall pumping schedule.

4. Test well Ca45-19 in the Laird Tract should be maintained as an observation well and for experimental and teaching purposes.

5. No additional wells should be drilled near the present Piedmont wells because of well interference. Such interference has already been demonstrated by other work taking place soon after completion of field work for this report.

6. Because of induced recharge from the stream to the well, protection of the quality of White Clay Creek water becomes important if test well Ca45-21 is converted to a production well.

7. Recharge areas (lineations) for the fracture zones should be protected from over-urbanization. Increased runoff due to the replacement of natural cover by impermeable man-made cover would result in decreased recharge to these aquifers.

8. One additional test well is warranted in the extreme northwestern portion of the Laird Tract.

9. Those University lands now in open space are serving as recharge areas and every effort should be made to protect them. Where construction must be done recharge facilities should be provided.

10. The area just north of Agricultural Hall should be considered as a possible recharge site.

11. The Manor Tract has potential for a small ground-water supply; up to 75 gpm might be obtained by a carefully developed system of small wells.

12. Up to 50 to 75 gpm could be obtained from a carefully developed well or wells on the Webb Farm. A suitable sand exists from 32-38 feet below land surface at the northern end of the property and several thin sands occur at various depths at the southern end of the tract. The most promising sand seems to be from 125 feet to 135 feet below land surface in the southeast corner of the property.

13. Up to 50 gpm might be obtained from the fine sands beneath the University West Farm.

14. The Main University Campus shows little potential for ground-water development.

15. Fractures and faults in the crystalline basement rocks beneath the Coastal Plain are possible potential sources of ground water. Sites for any test holes should be selected very carefully and should be preceded by a detailed seismic survey, if possible. Final site selection should take into account the direction and inclination of the fault plane as well as the thickness of the overlying weathered material. The weathered material is usually quite impermeable and may prevent adequate recharge from the overlying sediments into the fault zones below. All promising areas for such investigations are outside the University of Delaware property.

16. The waters collected in basements of University buildings and now pumped to waste could be used as boiler make-up water or some other service use outside that of human consumption.

17. Sewer lines are often located in potential well sites. However, if water is available at a site,

the water needs should be considered first and sewers should be isolated in accordance with the best engineering practice to avoid contamination.

Figure 11 partially summarizes the results of the study and indicates those areas where ground-water development is feasible.

This evaluation of the ground-water resources of the University of Delaware properties at Newark may be considered complete and definitive. The investigators are confident that no hidden resources of significant magnitude remain unidentified. The University lands serve a very important function in providing recharge to City wells already in existence and now, as a result of this study, a direct contribution of relatively large quantities of water can be made to the available supply. It is recommended that this additional resource be developed and distributed to augment the total water supply of the area. The University and the City should both benefit from such an arrangement. The University's contribution, in locating and providing access to the water, should be matched by the City's development and distribution of the resource in an equitable manner. Above all, the resource itself should be protected against over-development, contamination, or other abuses so that it may provide the maximum benefit to the community.

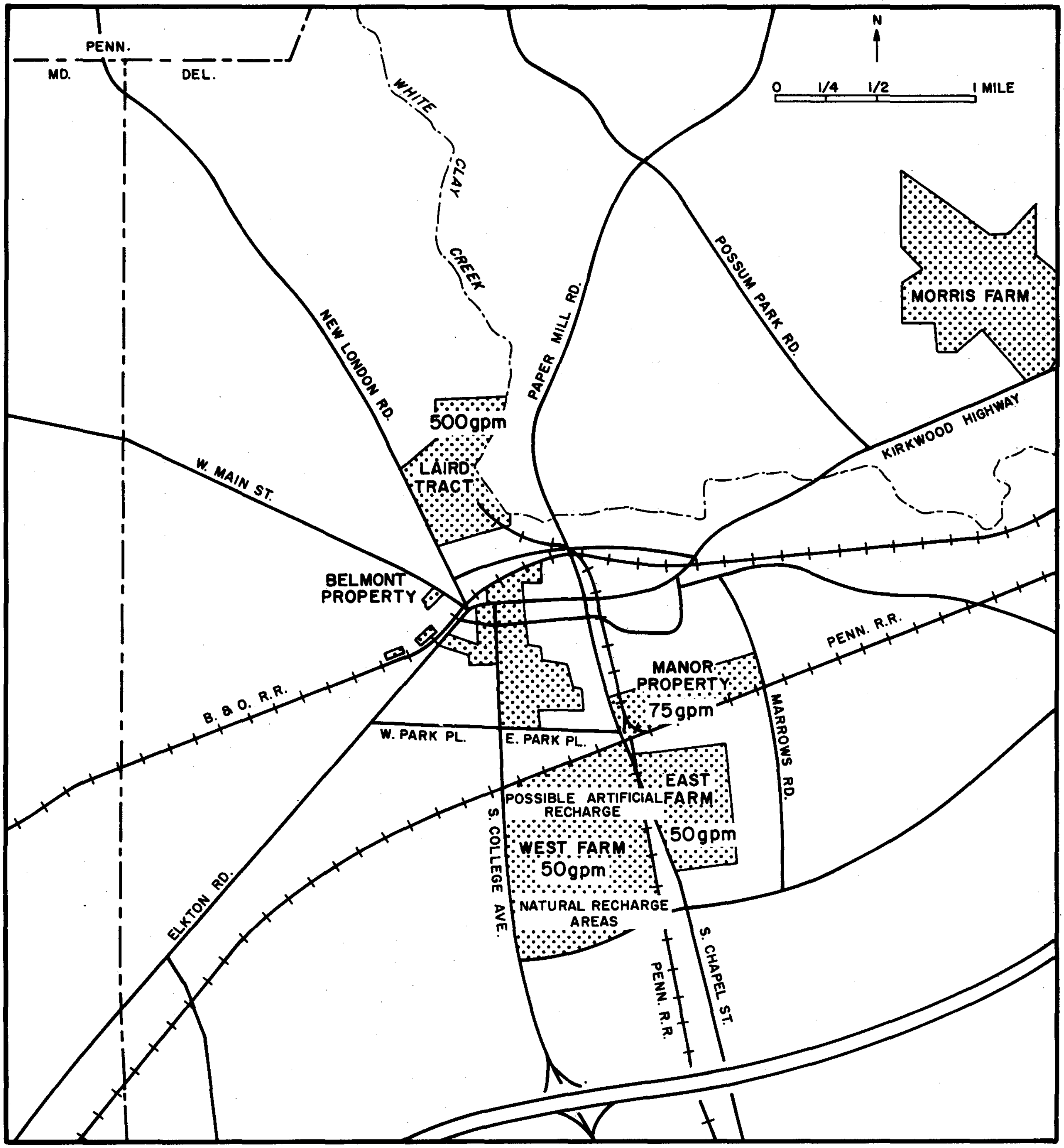


FIGURE 11. SUMMARY OF PROPOSED GROUND-WATER DEVELOPMENT ON UNIVERSITY LANDS.

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